THE DEVELOPMENT AND PERFORMANCE OF HIGH ENERGY DENSITY CAPACITORS

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Abstract

The US Army Research Laboratory has sponsored a capacitor development program for film dielectric capacitors that has yielded both superior capacitor performance and the ability to evaluate new polymers on a fast track. The performance of recently developed capacitors, projections for pulse power capacitors in the near term, and the development track for new polymers will be discussed as well as the ability to support efforts by both industry and academic researchers to bring new polymers to a finished film capacitor product quickly.

I. PROGRAM OBJECTIVES

The total requirements for high performance dielectrics used in capacitors that have been optimized for military applications is small when compared to commercial applications. Often, these specialty dielectrics require processing that is not commonly used for less demanding applications. As a result, it is difficult to maintain producers' interest in the continued manufacture of these specialty materials.

The goal of this program is to both provide a fast track for the development of polymers for high energy density capacitors but also to provide a plan for the production of the film, through the deployment phase, and for legacy equipment in future decades.

II. CHAIN OF MANUFACRURING

In order to meet the goals of this program a chain of manufacturing has been established from polymers to capacitors. The base materials all start outside the program, coming from both academia and industry. Whenever possible, the polymer and film manufacturing is kept in the hands of those best suited to handle those products. A secondary plan is devised so the military customer will be protected should the manufacturer choose to discontinue production of the specialty product.

An understanding of the manufacturing process is required in order to set up the secondary production plan. Often, the details of the process are held in confidence for use only should the manufacturer decide to discontinue production. Understanding the manufacturing process alone is not enough; the process must be demonstrated on independent equipment to assure the validity of the backup plan.

The backup plan equipment is usually done on a smaller scale than the production equipment. As such, it also becomes an ideal platform for the development of new polymers. Under this program, the chain of manufacturing is being made available to researchers developing polymers and films. Once a product is developed, it will be transferred to a commercial manufacturer if possible.

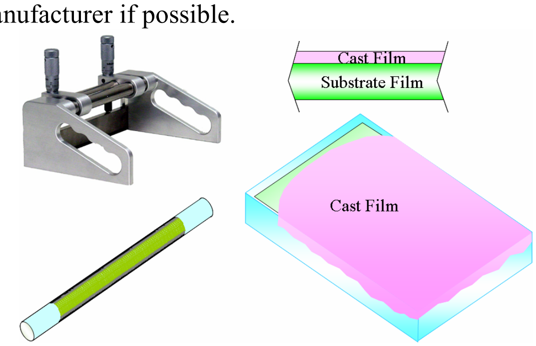

Figure 1 - Small Scale Solution Casting

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14. ABSTRACT
The US Army Research Laboratory has sponsored a capacitor development program for film dielectric capacitors that has yielded both superior capacitor performance and the ability to evaluate new polymers on a fast track. The performance of recently developed capacitors, projections for pulse power capacitors in the near term, and the development track for new polymers will be discussed as well as the ability to support efforts by both industry and academic researchers to bring new polymers to a finished film capacitor product quickly.

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Typical laboratory small scale equipment for solution casting film is shown in Figure 1. Normally a solution containing a small percentage of the polymer is placed on a substrate film and leveled using a doctor blade (upper left) or a wire wrapped rod (lower left). The volatiles are then removed from the solution through evaporation leaving behind the cast film on the substrate. The film is often exposed to UV for curing. After this has occurred, the cast film can be removed from the substrate. A similar process can be used when adding a coating to a dielectric film.

A small scale melt cast line is shown in Figure 2. Here the resin is loaded into the funnel (hopper) at the top of the device, heated, melted, compressed with screw drive and extruded through a flat casting die onto a casting drum. The film is cools and solidifies, after which it is wound onto a take-up reel.

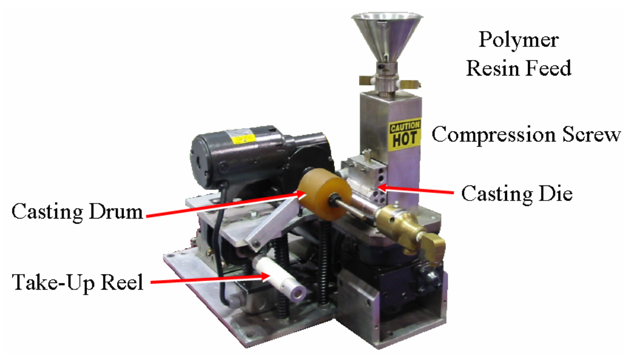

Figure 2 - Small Scale Melt Casting

The performance of cast films can often be enhanced by orienting the film after casting. In the laboratory, small samples measuring about 100mm on a side are put in a pentograph as shown in Figure 3, heated in an oven, and stretched in both directions until the desired orientation as achieved. The sample is then heat set (annealed) to lock in the orientation.

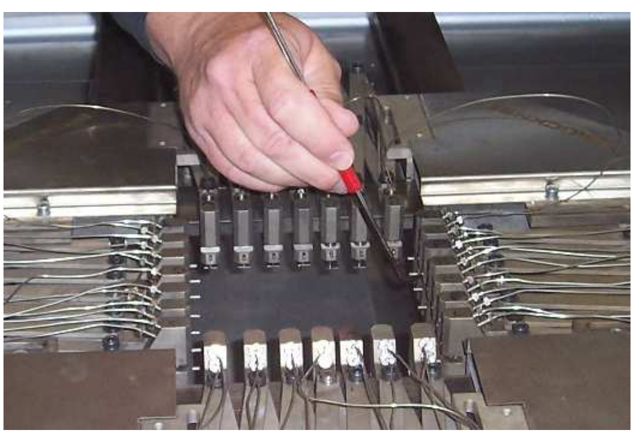

Figure 3 - Small Scale Film Orientation

The orientation of cast films has several significant effects on the film. The process makes the film thinner and it increases the crystallinity of the film. The increase in crystallinity normally leads to a higher breakdown strength and allows the dielectric to store more energy.

A schematic of the equipment used for continuously melt casting and sequentially orienting film is shown in Figure 4. The equipment is typically 30 to 100 meters from one end to the other and produces film that is 2 to 10 meters wide. To control the film temperature during the casting and machine direction orientation (MDO), the contact rollers are heated or cooled. The tenter frame is operated inside an oven with multiple heating zones where the traverse direction orientation (TDO) occurs.

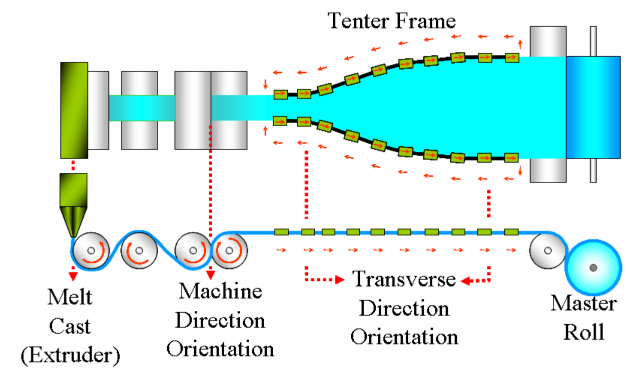

Figure 4 - Film Melt Cast & Orientation Schematic

Large scale solution casting of film can be done on a large casting drum or, more commonly on a substrate using a system like that shown in Figure 5.

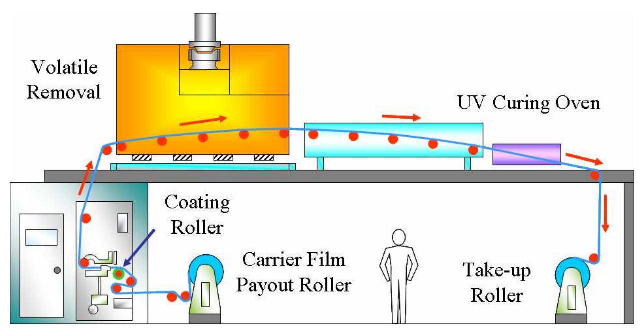

Figure 5 - Film Solution Casting

III. POLYMER FILM CONVERSION

Once the base polymer film is available, there is a series of processes that the film needs to go through before it is ready for capacitor production. Today's high energy density capacitors are constructed with a metallized electrode that is deposited on the base polymer film, normally using a vapor deposition process in a vacuum chamber as shown in Figure 6.

Often the optimization of the metallization process requires that the surface of the polymer be modified to change the surface tension and assure good adhesion of the electrode. This can be accomplished by exposing the film to corona or plasma treatment prior to mteallizaiton.

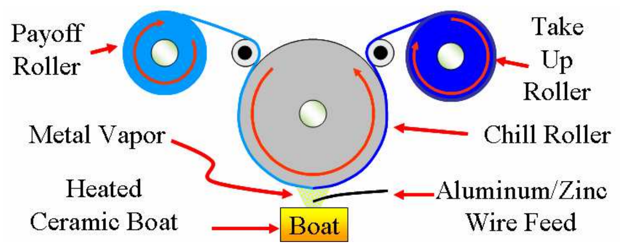

Figure 6 - Vacuum Vapor Deposition of Electrodes

IV. POLYMER FILM CONVERSION

The capacitor manufacturing process is also something that can be scaled. For the development process, the work is scaled so that materials can be evaluated at the smallest practical scale. In some cases this might be the area under a metallized dot a few millimeters in diameter used to evaluate rare polymers.

The next smallest test sample is the size of a postage stamp shown in Figure 7. This is commonly used to evaluate the performance of dielectric films available in limited quantities. Evaluating capacitors at this stage yields data on the dielectric constant and voltage stress capability of the film; both indicators of the films ability to store energy. The accuracy of the projections from stamp capacitor testing leaves much to be desired. The data often has a wide variance with values from competing samples overlapping. The tests do not provide information on the dielectrics ability to deliver energy in a specific time frame, which is often different than the ability to store energy.

Figure 7 - Stamp Size Capacitor

The true value of testing at the stamp capacitor stage is that the data eliminates dielectric films that perform poorly. This allows more time to be spent on the more promising materials. Also, two similar materials can be compared to determine which is likely to perform better.

The next step up, in terms of capacitor sample size is shown in Figure 8. These samples consumes about a kilogram of film per sample. These samples are essentially one element of a larger capacitor where hundreds of such elements would be connected together. Over the past decade and a half, testing of capacitors at this scale has consistently yielded the same type of data as full scale capacitors.

Figure 8 - Small Scale Capacitor

The needs of the US military for high energy density capacitors cover a wide range of applications. Many of these applications require that the capacitors operate at high voltages. For film dielectric capacitors, high performance at high voltage is normally achieved with capacitors that have been impregnated with a dielectric fluid. The impregnation process removes voids. The voids have a tendency to generate partial discharges that are associated with the early failure of the capacitors.

V. STATE OF THE ART CAPACITORS

With the wide variety of capacitor applications, it is very difficult to plot and project the performance of capacitors unless very specific performance issues are being evaluated.

A. Silent Watch Capacitors

One of the areas of focus for this development effort is energy discharge capacitors that remain charged for long periods of time. The duty cycle requires only a few discharges and the primary design parameter is the DC hold time for the capacitor. In a period of 18 months, capacitors operating at 1.3 J/cc went from operating for a few hours to well over 2000 hours. GA-ESI capacitor PN

38994 shown in Figure 9 was the first in a series of capacitors to demonstrate this capability [1].

Figure 9 - 2000 Hour, 1.3 J/cc Capacitor

B. High Energy Density Capacitors for EM Launch

Capacitors that are capable of handling 1000 charge discharge cycles in rapid secession with very little hold time is another area of focus for the program. The 50kJ capacitor shown in Figure 10 was the first high efficiency capacitor to achieve that goal with an energy density of 3 J/cc [2].

Figure 10 – 1000 Shot, 3 J/cc Capacitor

VI. PROJECTIONS FOR THE FUTURE

In light of the progress made to date and the amount of effort that is presently being expended in the area of capacitors aimed at military requirements, projections can be made concerning what the next few years are likely to bring.

- For the two types of capacitors described above, a cost reduction of greater than 30% in terms of $/Joule is projected over earlier capacitors.
- The energy density of the 2000 hour capacitors is expected to exceed 2 J/cc in 2009.
- The energy density of 1000 shot capacitors is expected to exceed 4 J/cc in 2009.

VII. CONCLUSIONS

The present work being done on capacitors for military applications has resulted in significant improvements in capacitor performance in the past few years. The level of effort is expected to continue and this effort holds promise of better capacitors in the energy discharge area as well as other areas of interest to the military.

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